UCRL- 92485
PREPRINT

DEVELOPING A SYNTHETIC COAL FOR A MODEL COAL SEAM

John E. Field
Douglas B. Fields
Charles B. Thorsness

This paper was prepared for submittal to the:
11th Annual Underground Coal Gasification
Symposium, Denver, CO, August 11-14, 1985

August 1985

Lawrence Livermore National Laboratory

DISCLAIMER

DEVELOPING A SYNTHETIC COAL FOR A MODEL COAL SEAM

by

John E. Field 1/
Douglas B. Fields 1/
Charles B. Thorsness 1/

ABSTRACT

In order to make a model coal seam for scaled modeling of coal burns, we have studied a variety of methods for creating a synthetic coal. Because it is desirable to burn the coal at a rate five times that expected in an underground seam, the synthetic coal needs to be assembled from coal particulates suspended in a suitable matrix material or bound into a macadam-like structure. The proposed dimensions of the model coal seam are 20'x 20'x 5'(2000 cubic feet). We propose to construct the seam on Lawrence Livermore National Laboratory (LLNL) property, at Site 300, about 15 miles east of the main facility. The paper discusses the problems of making an impermeable material, attaining a satisfactory burn-rate, the technical requirements of assembly, the cost of material and the logistics of the overall seam.

In the paper we describe our efforts to find a suitable binder for coal particles in a size range of 1/2 to 1 1/4-inches. Many were discounted due to the cost of materials, some would not retain the proper structure at elevated temperatures and others would not produce an impermeable mass. After the initial screening process we have selected a polyurethane foam binder as the best candidate. This binder has been used in a preliminary series of tests aimed at determining fabrication methods, permeability and roof-spall rate. These tests are described along with a discussion of environmental issues and future plans. We are continuing the small scale development and testing, and planning for a large scale burn, which is being held in abeyance due to funding limitations.

INTRODUCTION

In the past, studies on the growth of cavities in the Underground Coal Gasification (UCG) Project have been few in number, expensive and time consuming. Attempts have been made to improve on this situation by doing Large Block (LBK) tests on coal outcrops. Although these tests have reduced the cost of obtaining data by at least a factor of ten, even $400K, their cost, places severe limitations on the number and frequency of tests. Therefore, it is desirable to have a model seam of synthetic coal(SCS) conveniently located and inexpensive to operate; this would permit the operator considerable flexibility, a wide range of data and a short turnaround time.

1/ Lawrence Livermore National Laboratory, Livermore, California 94550.

The Lawrence Livermore National Laboratory (LLNL) has suggested a facility with a model seam having a 1/5 linear scale and a volume of 2000 cubic feet, which would make possible the set-up of a test in a week or so, and the completion of a test in 24 hours. It is estimated that the cost per experiment would be about $100K and that several tests could be done in a period of one year. Such a facility could study cavities in a wide variety of coals. The model seams could be constructed of blocks of coal from various mines or could employ a synthetic coal of particles from the same sources. A synthetic coal would be made from particles of coal and be filled and bound by a suitable material. The model seam would have injection flows 5 times that of normal UCG experiments to conform to scaling laws. (The rationale is further explained in the Appendix).

Construction and Costs of a Model Coal Seam

Site 300 is a special testing facility located 15 miles east of Livermore, California, and is operated by LLNL. Due to its size and remoteness, we are able to perform experiments that are very large and/or hazardous in nature. Even though the test location is remote, one can drive between the two facilities in less than 30 minutes. The Site 300 Plant Engineering Department has developed two site development plans and have estimated the cost of building a test facility for us. One plan would be located on flat ground and would utilize a pit into which the coal seams could be assembled. The other site is adjacent to that location. There we have looked at the possibility of cutting a berm across a small ridge on which we would install a concrete slab and vertical wall. The cost of construction for each of these plans is about $450K. This construction cost is not included in the operating costs given later. Figure 1 shows an experimental pad which is about 300 feet long and 200 feet wide. A concrete slab, 100' x 25', is shown as is a vertical wall which is shown rising against the face of the berm. This configuration will allow for easy assembly, the ability to add the overburden from above and make the clean-up relatively easy. The seam would be constructed as shown in Figure 2. Here the blocks of synthetic coal would be stacked and a matrix of thermocouple sets would be laid out between the layers.

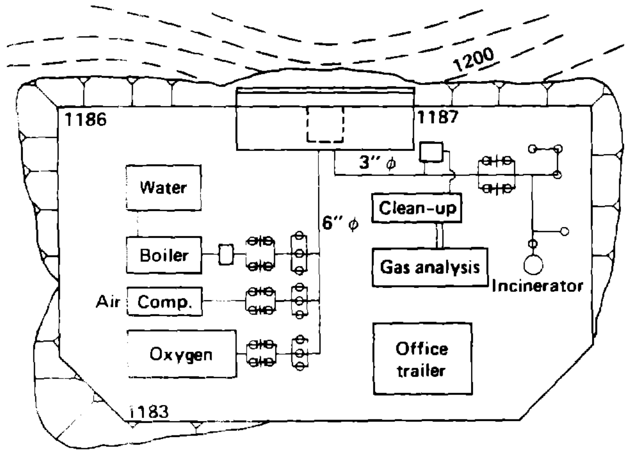

Figure 1. Plot plan of model coal seam.

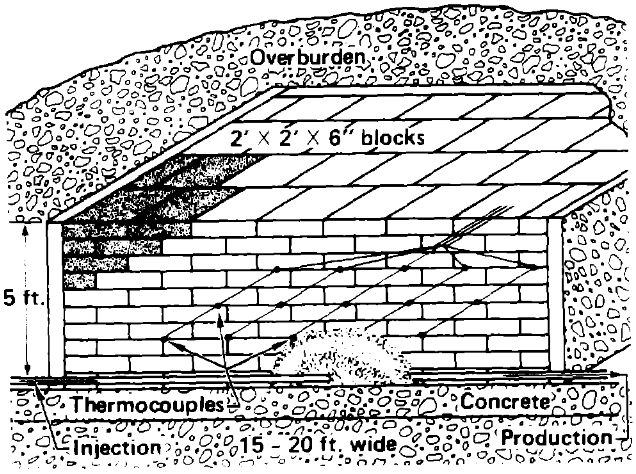

Figure 2. Isometric view of the coal seam.

Synthetic Coal Development

As stated earlier, we believe that the SCS would best meet the scaling requirements with a cavity burn rate five times as fast as the UCG experiments. The coal particles for the synthetic coal would be obtained from the mine of choice. The particles would be sieved to a preferred size range, cleaned and protected from loss of moisture content prior to the actual experiment. Procedures would be established which would insure that the characteristics do not change. Thus far, our experiments have been conducted on Wyodak stoker sized coal. Some of the coal arrives as mined and immersed in water, but some has been sprayed with Diesel oil to prevent drying. It is our practice to also immerse the oil sprayed coal in water as it arrives in Livermore.

Before making a matrix of synthetic coal we remove the fines and smaller particles. If the fines were not removed they would likely be blow out of the SCS by the high flow rates. We resieve the coal through a grating with 7/16 inch openings, producing a more suitable particle size range. As we continue to make experimental samples, we will probably narrow the range of particle sizes by lowering the upper limit. The void ratio of a volume of this coal is about 45 percent, which must be filled as well as be bound into a tight aggregate. The permeability of a synthetic coal will necessarily have to be quite low. We compiled a list of binder and filler candidates and proceeded to reduce its length for a variety of reasons. The binders considered were cement, plaster of Paris, plastic wood glue, epoxy (epon and versamid), water emulsified petroleum tar (SS-1h), coal tar, resin and asphalt. The potential fillers were: fines of coal, sand and styrofoam beads. Because the cost of epoxies and glues were high and difficult to use they were set aside. Several experiments led us to believe that the better choice would be water emulsified tar (asphalt), but as we continued to test it we found that it did not behave well. Cement restricts the tests to high ash content.

The potential of using injected polyurethane suggested the solution to several problems. First, it would eliminated the need for transporting and handling hundreds of cubic yards of coal. It could eliminate the need for bulk storage and disposal of these materials and the binders. It would eliminate the need for heavy equipment for assembly, except for the overburden. It would reduce the total amount of coal that would be required, due to the reusability of a large portion of the material. And, finally, it would permit a crew of two men to assemble a seam in a few days, in the manner of an igloo, with no more than a forklift or jib crane.

The envisioned system would allow inexpensive laborers, near the mines, to make coal-foam blocks 2'x 2'x 1/2', wrap or bag them in plastic and ship them to our test site. The large 2 x 2 area of each block would allow the seams between the blocks to be adequately staggered and filled with the same foam like mortar. Between the layers we would use a 1/4" thick impermeable layer of flexible foam. The use of this horizontal layer of sheet foam will make assembling easy, and the cleanup will be facilitated by eliminating a cutting plane. See Figure 3.

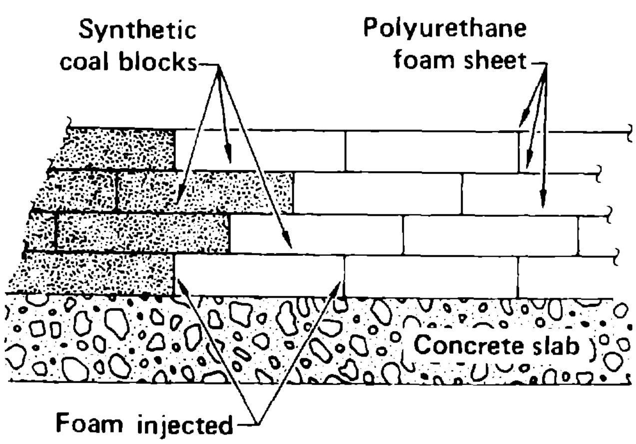

Figure 3. Close-up section of a block assembly.

Polyurethane can be supplied in a variety for densities, the most common of which is 2 lbs per cubic foot. Typically, the foams used for insulation and floatation gear expand forty to one from the liquid volume. The cost of the material is about $1.20 per pound and the injection equipment costs $3K to $15K. Based on a void ratio of 45 percent, the foam cost of making 2000 cubic feet of simulated coal would be about $22K. This includes about 20 percent waste and some deviation in the foam density. The cost for the second experiment would be about $10K-12K because most of the coal blocks can be retrieved as the experiment is being disassembled. By prorating the cost of the injection system and adding the labor necessary to make the coal blocks, the cost of the coal, the transportation cost, it would appear that the cost per experiment would be in the range of $25K to $30K. This does not include the facility construction, the seam assembly cost and the cost of operation. The total cost per experiment, excluding the facility construction, appears to be about $100K.

Testing the Synthetic Coal

The suitability of any synthetic coal must ultimately be determined by testing under the conditions of its expected use, but, since that requires an expenditure of $500K, we have tested our samples in the laboratory first, on a small scale. The purpose of the tests is to determine if the coal matrix will behave in a manner analogous with the larger seam, but substantially faster. The two parameters that might suggest the rejection of any synthetic coal are excessive permeability and a cavity growth rate that is too slow for scaling purposes. We have tested the permeability of polyurethane samples using a standard flow testing apparatus and have found the permeability to be on the order of microdarcies. Since we had determined that a permeability of several millidarcies would suffice, we have not made further tests using a coal composite. Rather, we have used the available time for determining weight loss of a composite and, hence the growth of the cavity, as high temperature gas passes across its surface.

As can be seen in Figure 4, the sample is suspended above a hot gas source by a load cell. Hot nitrogen gas flows in from the bottom and passes across the lower surface of the sample. By using an inert gas instead of actually burning the coal, we are able to report the data in terms of temperature effects. Thermocouples are imbedded in the sample in one inch increments from the exposed surface. When the hot gas is introduced to the test chamber and the temperature of the gas approaches the controlled value, which is the steady-state output temperature (Tc-9), the foam chars, the coal yields its gases and debris accumulates on the bottom of the chamber. The imbedded thermocouples (Tc-1 through Tc-6) give us an indication of the cavity growth and indicate the insulating characteristics of the polyurethane foam.

We have tended to call this experiment "spall rate," but that is a misnomer because we really do not measure the rate at which the coal falls from the sample surface. We record the loss of weight of the sample versus time and, after the experiment is completed, we weigh the amount of residue in bottom of the container.

Results of Weight Loss Tests

There have been six tests to date and several more are scheduled. Of these tests we regard only three to be reportable as numerical data. The first three tests (RF-1,-2 and -3) were done to gain a quick look at the behavior of the coal-polyurethane composite.

The samples that were tested under more controlled conditions are referred to as RF-4, RF-5 and RF-6. Each of these samples was subjected to a temperature higher than the one preceding. The weight loss versus temperature is shown in Figure 5. The three points,

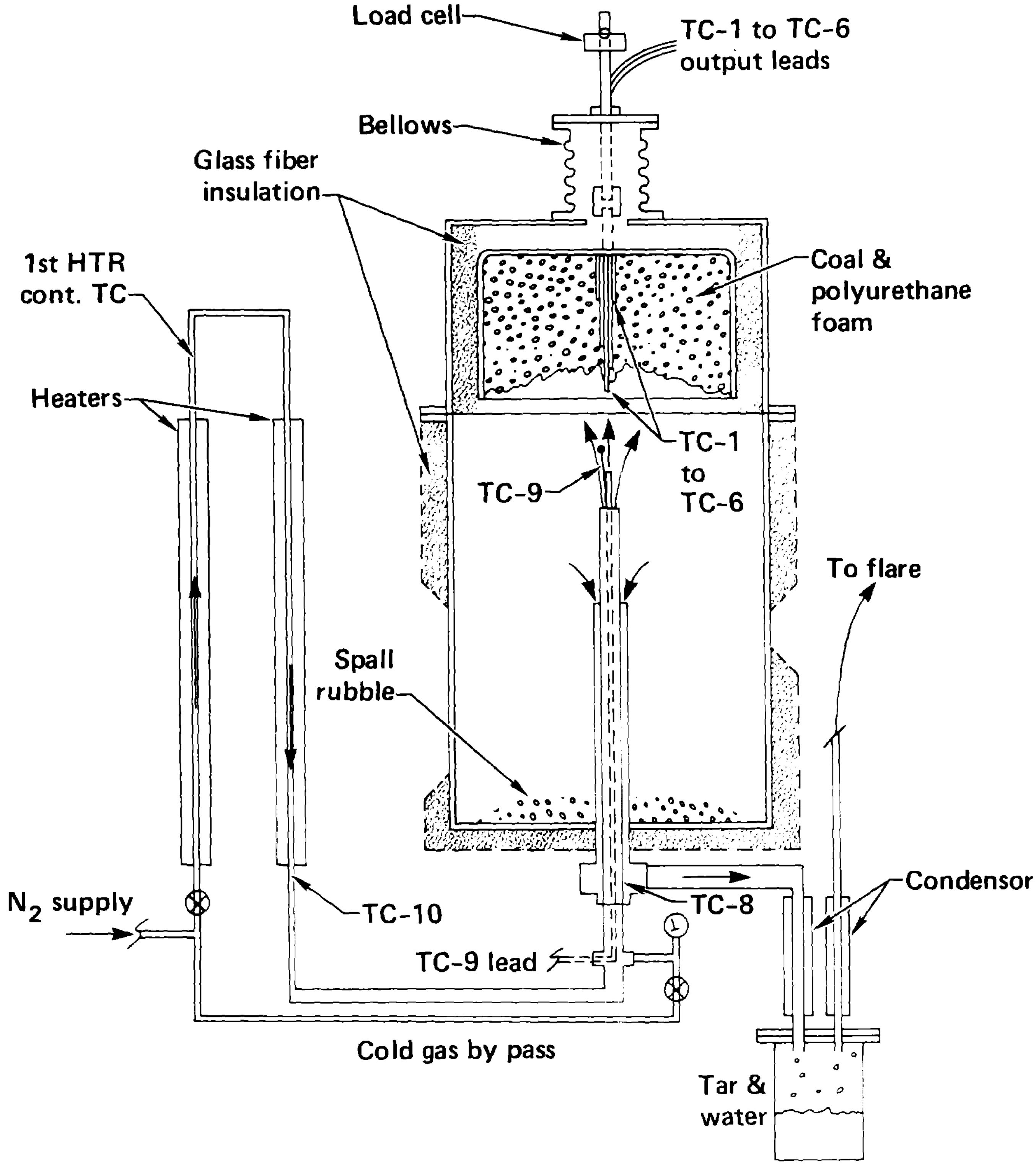

Figure 4. Synthetic coal weight loss apparatus.

Table 1. Data from RF-4, RF-5 and RF-6.

Sample No.	Coal Wt.	Foam Wt.	Temp.(T-9)	Gas Produced	Residue
RF-4	2551 gr.	174 gr.	540 C	918 grams	365 gr.
RF-5	2610 gr.	*124 gr.	550 C	1028 gr.	*711 gr.
RF-6	2587 gr.	190 gr.	580 C	1164 gr.	365 gr.

* Note: Due to problems in injecting the foam there were voids that remained in the RF-5 sample can that allowed a much larger portion of the synthetic coal to fall as residue. This is attested by the low Foam Wt. and the large Residue above.

representing the three experiments, were take from the data by allowing the temperature at Tc-9 (the output gas) to level off, then, the weight loss is determined over a one hour period. This graph should not be considered as highly accurate, but is intended to show relative values for increased weight loss versus increased temperature. Figures 6, 7 and 8 show some computer plots of the data. As further data points are obtained we expect to produce a more accurate plot.

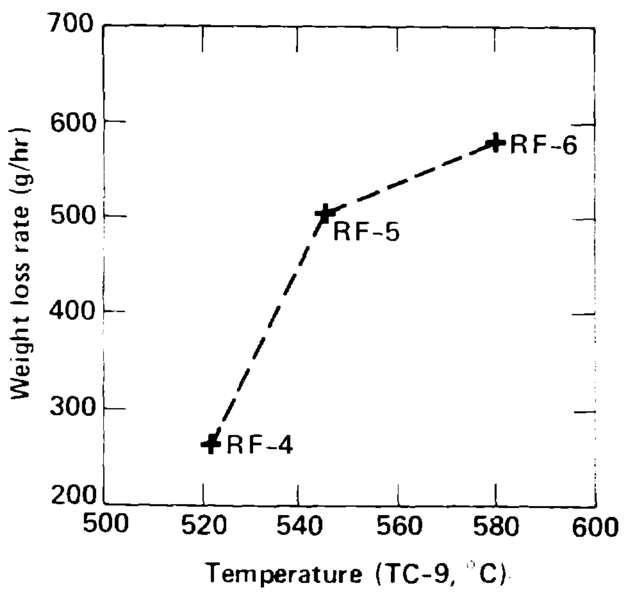

Figure 5. Weight loss versus temperature.

It should be understood that no test of this type will be able to replicate what occurs in UCG. The main purpose of doing these tests has been to characterize how the polyurethane behaves, as temperature increases, and that, as a matrix, it will also behave much like low density coal. To date, the experiments have been positive in nature, but they have not established a clear and accurate set of parameters that will extrapolate into a larger scaled experiment, much less a UCG experiment. However, continued testing at greatly increased temperatures and the transition into larger experiments will soon reveal the viability of this approach.

Future Synthetic Coal Experiments

Two tests are planned that will establish the efficacy of the synthetic coal. First, we will do a 30-gallon barrel test in which we propose to do ignition and burn. We are proposing to have an optical port through which we can observe the actual burn. In addition, we propose to assemble blocks of synthetic coal into a firebrick lined container. The size of this Model

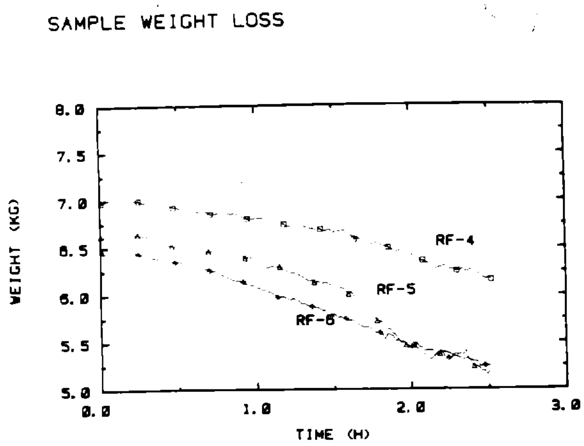

Figure 6. Sample weight loss for RF-4, 5, 6.

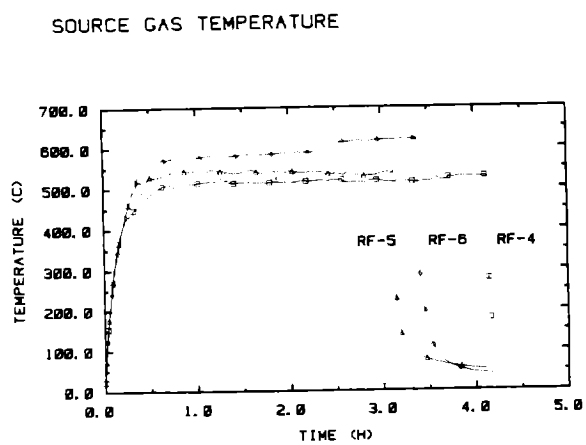

Figure 7. Source gas temperatures for RF-4, 5, 6.

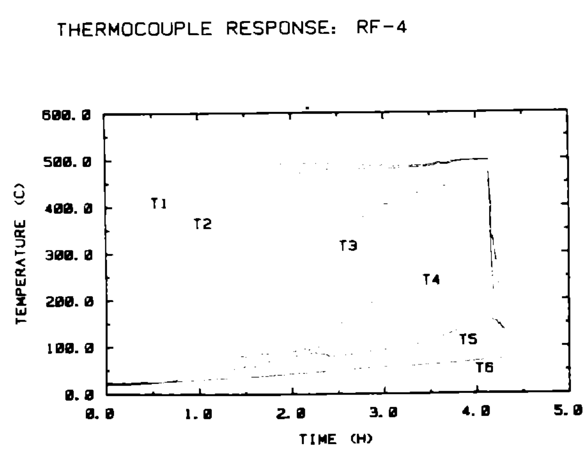

Figure 8. Thermocouple response: RF-4.

Seam prototype will be about 4' x 4' x 6', or about 100 cubic feet. This experiment will also be a full burn demonstration, but will not require the facility at Site 300. The gases from this later test will be fully analyzed and the by-products will be burned-up in a propane flare. Although there are no current plans to fund the large SCS facility, we feel that the development of a scalable synthetic coal, with properties that can be easily varied, will be useful for future testing when funds are available.

APPENDIX

Rationale for a Model Coal Seam

We have been formulating plans to simulate coal gasification in a 1/5 field scale, laboratory setting. By using synthetic coals it is possible to obtain precise data relating to underground gasification cavity growth. Field tests do not allow sufficient control of conditions or monitored carefully enough to yield definitive data on the evolution of the underground system. In addition, field tests are very expensive, precluding the possibility of doing an experimental series. Because small scaled models may not adequately represent a prototype system we believe a relatively large model, a 1/5 scale, will increase our knowledge of the UCG process. The objectives of the 1/5th scale model are:

1. A scaled simulation of a real coal seam.
2. Investigation of process parameters vs cavity geometry(e.g. flow rate, injection gas composition, coal properties).
3. Development of process models.
4. Testing of process equipment.

The proposed tests would be conducted near Livermore, California, using a specially constructed pad with a maximum of 2000 cubic feet capacity.

SCS tests will not be inexpensive, but they will be considerably less expensive than large block (LBK) tests, which cost $400K, and orders of magnitude cheaper than full scale field experiments.

The choice of the 1/5th length scale implies that the total volume of the consumed coal should be 1/5 cubed or 1/125. To maintain flow similarity, the Reynolds number should be the same as for a prototype system. Therefore, the gas flow per unit area in the model should be 5 times that of the prototype. Based on this flux and coal consumption the time scale of the model should be 1/5 squared or 1/25. This figure is also arrived at using fundamental heat conduction equations. Cavity development tests require that the model system wall and roof rates be properly scaled, but due to processes that are still poorly understood there is no way to prove that the scaled rates are accurate. This simple model postulates that the conversion of coal in cavity rubble is controlled by heat transfer considerations near the wall. We assume that when the wall reaches a certain temperature it is converted from wall to bed. We further assume that the Nusselt number is dependent on the Reynolds number in the bed region. If the Reynolds number of the prototype and the model are the same, and the synthetic coal falls apart at the same temperature as real coal, then the wall growth is properly scaled. The rate of a simple model of spalling is probably tied to the rate of penetration of a thermal front into the coal and some failure length scale. The penetration of a thermal wave is roughly proportional to the square root of exposure time. So we have

$$ls = K\ t\ \exp 1/2$$

$$\text{Roof rate} = ls\ /t$$

where ls is the spalling length, t is the time for a thermal wave to move ls and K is a constant dependent on solid properties. By solving the first and substituting into the second we find that

$$\text{Roof rate} = K/t$$

Therefore, if the spalling length scale is 1/5 of the prototype length, the roof rate will be 5 times the prototype, which is required to maintain similarity.

Of concern is the possible movement of small particles by the gas flow. In the field system particles less than 0.5 mm would be fluidized. On the other hand, in the model system, particles of 0.25 cm would move. This would suggest that particles no smaller than 0.5 cm should be used.

There are some phenomena that cannot be scaled such as the gas residence time and free convection. Gas residence time is important if the reaction kinetics are such that important reactions are evenly distributed, which is not the case. The reactions of char/oxygen, steam/char and drying probably take place in thin zones in the prototype, and the thinness is preserved in the scaled system. The location of these zones are preserved by geometry and flow scaling. That free convection is not preserved is indicated by the differences in the Grashof number. The Grashof number in the model is as much as 3000 times smaller than the prototype value. This is a result of the density and strong length dependence which cannot be compensated for in any other adjustable parameter. If the Grashof number is small it does not need to be preserved. However, it appears that it could be as large as 10 exp 10 in the prototype making it potentially important. Free convection is most important in the large void above the cavity rubble. In this region it could play a significant role in transferring energy from the bed to the roof, however, estimates indicate that radiative transport is 30 times greater than the free convection transfer, and not scaling free convection may be acceptable. The free convection transfer and not the scaling free convection may be acceptable. However, if free convection heat transfer is not important, free convection mass transfer probably is significant in the void, since there is no mass transfer analogue to radiation which could swamp it. The importance of modeling the mixing in the void is not clear, but we recognize that the free convection effects of all types are more important in the prototype than in the model. The primary parameter that we will not model is pressure, since we will provide only a small amount of earth cover. This means that the formation of methane cannot be adequately addressed. However, parts of the methane issue involving the survival of methane by pyrolysis can be addressed. Also, the role of large scale collapse cannot be directly addressed. Parameters which can be explored are flow rate, injection gas composition, seam thickness/overburden, ash and water content of coal, influence of certain measurable coal mechanical properties, and the injection of water/oxygen mixtures. Other candidate issues are: the influence of well geometry, the role of stringers, the effect of multiple CRIP cavities, the differences in high and low volatile coal cavities, the performance of open hole and char filled links, and the utility of new in situ diagnostic techniques.

It is important that the SCS experiments yield time resolved data for cavity growth, since this is most lacking in field data. We plan to rely on a large number of thermocouples and use careful post experiment excavation procedures to correlate temperature readings with cavity features. We are considering the possibility of visually inspecting the cavities using TV equipment. This technique is only workable if it can be shown that the stopping and restarting process does not unduly alter the course of gasification. Finally, we will consider the use of HFEM and acoustic methods if the expense is reasonable and the accuracy proves to be a useful supplement to thermocouple data.

ACKNOWLEDGMENTS

We thank Gordon Spellman and Phil Fleming for their recommendations on plastics technology. We also wish to recognize the efforts of Nuri Ozgen, of Kaiser Engineering, who studied the various matrix options and obtained many of the cost factors.

This work was done under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.